Modeling the Impact of Extreme Events on Margin Sedimentation

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Award Number: N00014-04-1-0168

LONG-TERM GOALS

To understand the mechanics of hyperpycnal flow generated from the plunging of small and medium size rivers and how these extreme events affect the transport of terrestrial sediment and how they influence the mixing processes in the coastal ocean.

OBJECTIVES

- To develop a two dimensional vertical structure finite volume model of density and turbidity current

- To verify this model against available experimental data.

- To apply the model at the field scale to study the affect of stratification on a plunging density current.

- To study the generation of internal wave by the passage of a hyperpycnal flow (turbidity current).

APPROACH

A two-dimensional vertical structure model has been developed. This model solves the Reynolds-averaged Navier-Stokes (RANS) equations along with species mass conservation equations for non-orthogonal structured grid in order to obtain flow variables that are non-uniform over depth. Closure for the turbulence stress terms is obtained by using the buoyancy modified k-ε model. The governing equations are discretized using an implicit finite volume scheme for non-orthogonal grid system. In this method, non-orthogonality has been addressed in the process of approximating the convective and diffusive flux through the cell face without transforming the grid to an orthogonal curvilinear co-ordinate. Collocated arrangement of the variables has been used for the present grid system. For the approximation of the convective and diffusive terms in the governing equations, we used differed correction approach which is a blend of lower order scheme (e.g., first order upwind scheme, UDS) with higher order scheme (e.g., second order central difference scheme, CDS). An implicit three-time level second order scheme is used for time integration. Strongly Implicit Procedure (SIP) has been used in order to solve the discretized governing equations by iteration. The pressure correction equation developed from mass conservation equation is solved using the PISO (Pressure Implicit with Splitting of Operators) algorithm. The present model allows specification of different types of boundary conditions depending on the nature of the flow. At the inlet boundary, distribution of all

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2004**	2. REPORT TYPE	3. DATES COVERED **00-00-2004 to 00-00-2004**
4. TITLE AND SUBTITLE **Modeling the Impact of Extreme Events on Margin Sedimentation**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Civil and Environmental Engineering,,University of South Carolina,300 Main Street,,Columbia,,SC,29208**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

dependent variables should have to be prescribed. At the outflow boundary, normal gradients of all dependent variables are set to zero, i.e., variables at this boundary are extrapolated from the interior domain. Open surfaces are treated as symmetry boundary condition where zero convective and diffusive flux is considered across this surface. At high Reynolds number flow, the viscous sub-layer near a solid boundary is so thin that it is difficult to use enough grid points to resolve it. Therefore, at the solid boundary, velocity profile is set using the wall functions approach.

The work has been primarily carried out by a doctoral student Sadia M. Khan and it contributes to her dissertation.

WORK COMPLETED

- A 2-D vertical structure finite volume model of density driven flow has been developed. The model utilizes the buoyancy modified k-ε model for turbulence closure. A non-orthogonal grid system has been used in the model that can handle a wide variety of boundary conditions.

- The model has been verified against two sets of experiments on the generation of internal waves by the passage of a gravity current in a stratified flow. In one, the current is released over a ramp and in the other, the current is released on a horizontal bed. In both cases, the model captures the generation of internal waves and other aspects of the flow and matches the experimental results satisfactorily.

- The model has been applied at a larger scale to study the interaction between a plunging density flow and a stratified environment. It has been found that the passage of a hyperpycnal flow generates a solitary wave with its maximum amplitude occurring above the head of the current. We will continue our numerical experiment by considering stratification data obtained from the field by researchers involved in the STRATAFORM and EuroSTRATAFORM Projects.

RESULTS

The model has been verified by comparing the model prediction with experimental results. For this purpose, we have considered two sets of experiments carried out by Maxworthy et al. (2002) and Monaghan et al. (1999). In the first experimental setup, internal waves have been generated by density current in a tank with horizontal bottom (Maxworthy et al. 2002). They have run several experiments for sub- and super-critical flow conditions where heavy fluid was released from behind the lock gate to the lower boundary of the tank containing linearly stratified ambient fluid. The second set of experiments carried out by Monaghan et al. (1999) generated internal solitary wave when density current was descending down a ramp into a two-fluid system. We have run our model using these two experimental setups and found that model predictions are in good agreement with the experimental results. Figure 1 shows the comparison of some of the model result with the experimental results of Maxworthy et al. (2002).

After validation of the model, we applied it to study the generation of internal waves due to plunging of a river. We considered a 1000 m long domain with Steep bottom slope of 3^{o}. Boundary conditions used in this case can be summarized as follows: at inflow boundary (1.3 meter of depth), it is considered that a river is continuously discharging heavy density water (density around 1045 kg / m^3) with a constant velocity of 1.625 m/s. For initial stratification, linear density profile is considered for the ambient ocean water, i.e., we assumed constant density of 1026 kg/m^3 at the top surface and it will linearly increase with depth. Figure 2 shows the time sequence of the evolution of density current into a linearly stratified medium due to plunging of river. It is observed from the results that a large amplitude solitary wave develops above the head of the density current. After plunging into ocean, the density current has created disturbance in the stable ambient ocean stratification. Figure 3 shows the intense mixing occurring in the water column just at the location of the current head after 800 seconds. The detailed results will be published in a peer reviewed journal. A manuscript is currently under preparation.

IMPACT/APPLICATIONS

The development of the numerical model of density current provides an opportunity to study the impact of density driven flow on the generation of internal waves. Internal waves are common oceanographic phenomenon which results from disturbances created into stable ocean stratification. These waves can lead to vigorous turbulence and mixing in the water column. Internal waves can also significantly affect the acoustics. Recently, researchers have been paying attention to the density currents as a potential force for generating internal waves. Density currents can be generated by retrogressive slope failure, storm, or due to the plunging of a river. The non-depth-averaged model developed here allows us to study whether a density current can generate an internal wave and how the passage of the density current affects the stability of a stratified environment.

TRANSITIONS

We consider that the development of a vertical structure model of density driven flow is an important progress towards understanding the complex interaction of plunging river flow, stratified environment of the ocean, and the bottom boundary. We plan to incorporate an erodible bottom boundary to the model. We also plan to study the convective sedimentation process using this model. Experimental data from the work of Jeff Parsons will be useful for this purpose. The model can also be incorporated in the *3-D Sedflux* model of James Syvitski.

RELATED PROJECTS

This project is closely related to an NSF funded project "CAREER: Experimental and Numerical Modeling of Flow and Morphology Associated with Meandering Submarine Channels" and an industry funded project "3-D Numerical modeling of turbidity current." The model will be further verified and applied at the field scale using stratification data obtained by field researchers involved in the EuroSTRATAFORM Project.

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Monaghan, J. J., Cas, R. A. F., Kos, A. M., Hallworth, M. (1999). Gravity current descending a ramp in a stratified tank, *J. Fluid Mech.*, 379, 39-69.

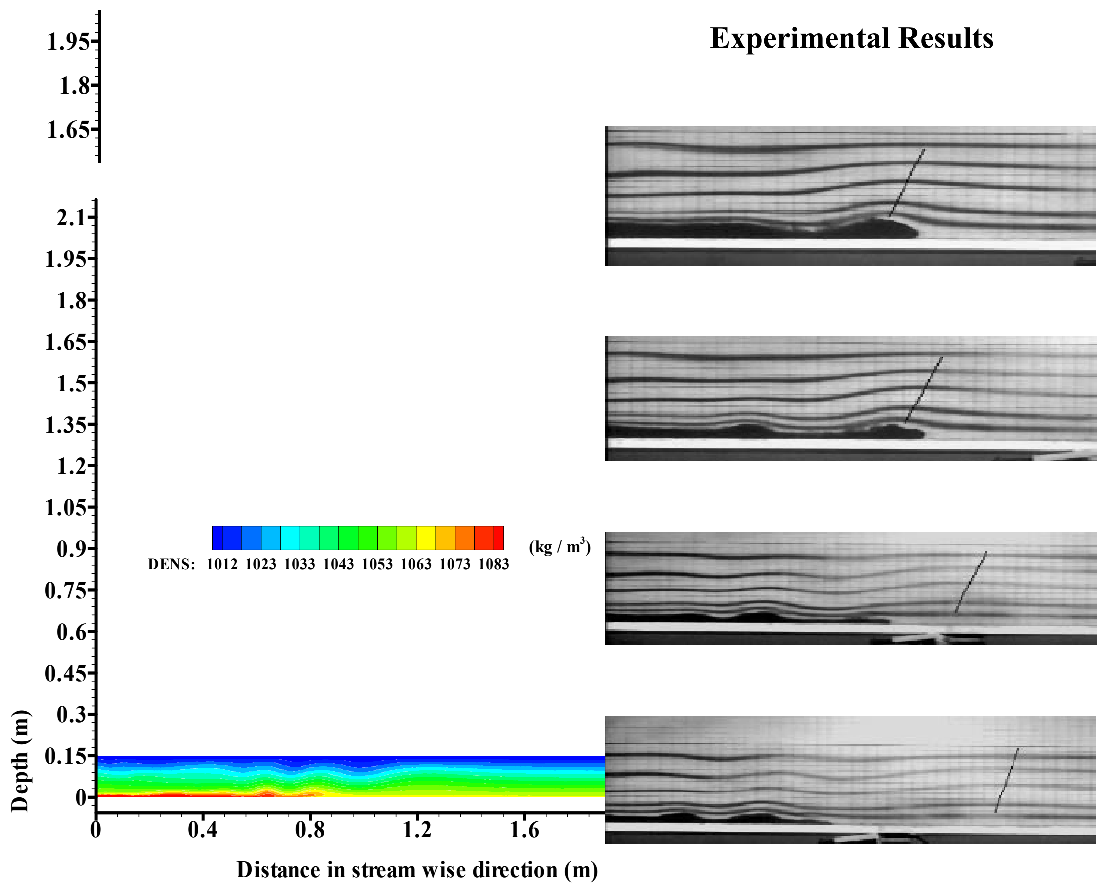

Figure 1. Comparison of the model prediction with experimental results. Left: simulation; Right: photographs from experiment of Maxworthy et al. (2002). Time sequences are (a) 4s; (b) 6s; (c) 10s and (d) 12s after opening the gate.

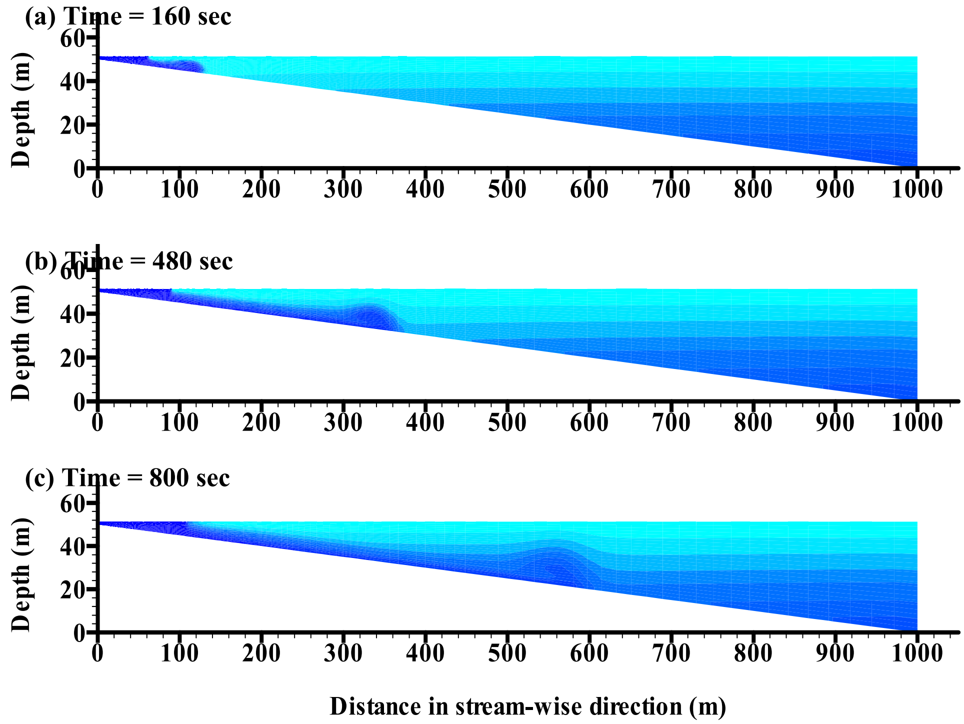

Figure 2. Time sequence of the generation of internal solitary waves due to the plunging of a density current in a linearly stratified medium.

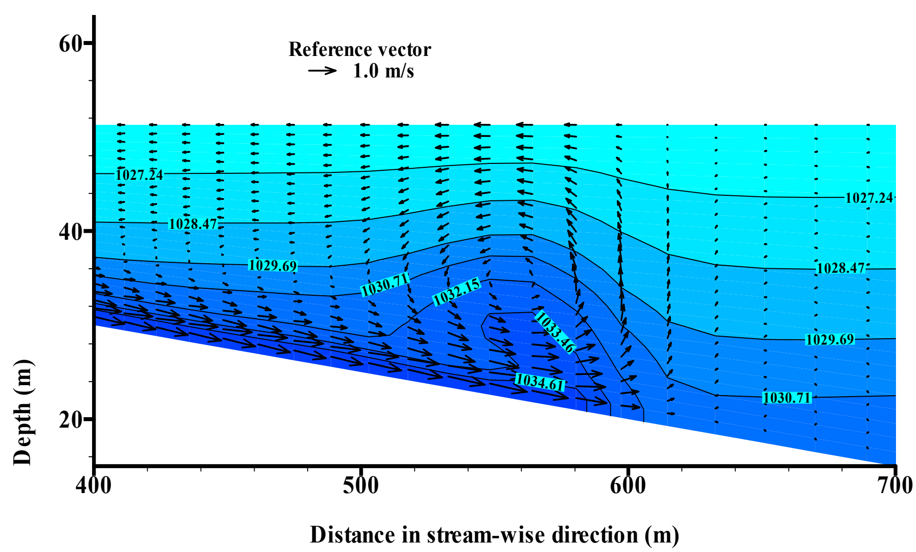

Figure 3. Intense mixing occurs near the head of the current shown in Figure 2.